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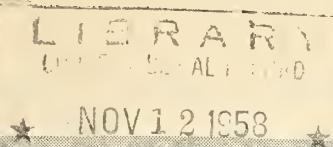




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HOME ECONOMICS RESEARCH REPORT NO. 6



U. S. DEPARTMENT OF AGRICULTURE

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**automatic  
clothes dryers**

—their performance  
and effect on certain  
fabric properties + 3a

3b  
● AGRICULTURAL RESEARCH SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE

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This report is part of a research study on the functional requirements, use, and care of the home and its equipment, and supplements research in the Clothing and Housing Research Division on the care of fabrics in the home.

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# automatic clothes dryers—their performance and effect on certain fabric properties

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and others. ✓

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## SUMMARY

Automatic clothes dryers, their various design features, and factors affecting performance were investigated in evaluating home drying methods and their effect on fabric properties. Operating characteristics of the dryers were also determined.

In the study, fabrics were dried in automatic gas and electrically heated tumbler dryers, in an electrically heated cabinet dryer, and, for comparison, on indoor racks, and on outdoor lines protected and unprotected from the sun. The automatics included dryers with perforated and nonperforated drum, single and selective thermostat settings, and dryers designed for operation on 120- and 240-volt circuits.

Tests were made with 14 white fabrics and 21 dyed fabrics in a variety of colors. All the fabrics were types commonly laundered in the home—sheetings, toweling, and clothing fabrics. Fibers included cotton, linen, acetate, viscose rayon, and nylon.

In some of the experiments the samples were prepared for drying by soaking in clear water; in others they were washed in a detergent solution and rinsed. Moisture content of the wet load was controlled to within  $85 \pm 2$  percent of the dry weight, except when moisture was an experimental variable.

The effects of different drying methods on fabrics were evaluated in terms of measured color changes, chemical degradation, bursting strength, and dimensional change; in some instances visual observations were also made.

*Effect of drying method.*—Results of 100 dryings of 14 white fabrics that had been soaked in cold water between dryings showed that no one method consistently caused the least or the most change in all of the fabric properties analyzed. In outdoor drying occurred the most chemical degradation in 13 of the fabrics, and the most graying and

loss of bursting strength in the largest number of fabrics. Tumbler dryers caused the greatest shrinkage and visible wear; the gas dryers caused the most yellowing. Inside rack and electric cabinet drying usually caused the least change in any fabric property.

In the study of white fabrics washed in a detergent solution between dryings, gas and electric tumbler dryers, and outside line and inside rack were used for drying three cottons, a nylon, and an acetate-viscose rayon.

Washing between 50 dryings, compared with soaking only, lessened but did not completely eliminate graying in all fabrics, and decreased yellowing in cottons but not generally in the other 2 fabrics. Judges' scores indicated that the washed cottons dried by all methods were satisfactory, but some of the nylon and acetate-viscose rayon samples were not. Usually the higher the acceptability score, the less the fabric had yellowed. From the standpoint of bursting strength no one drying method stood out as best or poorest.

The dyed fabrics, washed in detergent solution and rinsed, were dried 50 times on outdoor lines unprotected and protected from the sun, and in gas and electric tumbler dryers. Most of the fabrics were lighter in color, as indicated by gain in reflectance, when dried outdoors in the sun or shade than when dried by the other methods. In the greatest number of the fabrics, particularly the greens and reds, the most color change was brought about by sun drying. In some of the blues, gas drying made the most change.

For the washed dyed fabrics, bursting strength differences between methods were not significant. As with the white soaked fabrics, dimensional changes in the warpwise direction, mainly shrinkage, were usually least for the samples hung on the line or rack and greatest for those tumbled.

*Effect of dryer design features.*—The effect of operating voltage on performance was compared by use of two pairs of dryers, in each of which the dryers were identical except that one was operated on 120 volts and the other on 240 volts. The 120-volt dryers took about twice as much

time but used about the same amount of electrical energy as their counterparts operating on 240 volts. The differences between the 120-volt dryer and the 240-volt in graying, yellowing, chemical degradation, bursting strength, and scores for appearance of the fabrics did not indicate a superiority of one operating voltage over the other.

A comparison of the effects of perforated- and nonperforated-drum dryers used to dry 14 white fabrics indicated no conclusive superiority of one type over the other.

The thermostat setting—high, medium, or low—made little difference in graying, yellowing, loss of bursting strength, and dimensional change in fabrics dried in a gas and an electric dryer. Differences in chemical degradation, although sometimes statistically significant, were relatively small except for the two nylon fabrics in the gas dryer. They showed increased damage as the thermostat settings were changed from low to high.

*Effect of factors related to load.*—The study included investigation of the possible advantage with respect to use of time and electrical energy that might be gained by separating loads of mixed fabrics into single-fabric loads for drying. With two 6-pound loads, each consisting of 3 pounds of terry towels and 3 pounds of sheets, both time and electrical energy were saved when the items were separated after water extraction and dried as one 6-pound load of towels and one 6-pound load of sheets rather than as two mixed loads. In contrast, one mixed 6-pound load required less time and energy when dried without separation than when dried as one 3-pound load of towels and one 3-pound load of sheets.

After the time necessary to dry an 8-pound mixed load wet to 50 percent of its dry weight had been determined, it was found that additional 5-minute intervals dried 15 percent moisture increments up to 140 percent. Each additional 5-minute interval required approximately 0.4 kilowatt-hour of electricity or 1.7 cubic feet of gas.

*Operating characteristics of dryers.*—As indicated by thermocouple readings, in all dryers maximum exhaust temperatures were lower than those inside the drum near the door. Temperature-indicating crayon marks on fabrics indicated higher fabric temperature than that of the air near the door for some dryers and less for others; at both locations the high settings were approximately from 30° to 50° F. higher than the low

with the medium setting falling between. Further research is needed on methods to determine accurately the maximum dryer and fabric temperatures reached and their duration within the dryers.

Efficiency of dryer operation, as measured by the units of heat energy used per 1,000 grams of moisture removed from loads, was not affected by thermostat setting or by operating voltage. However, differences in operating efficiency were found among the individual dryers studied. Time for drying the same load varied only slightly when dryers were operating under like conditions.

*Time used by operator.*—To place and remove a load from a tumbler dryer took about 10.5 minutes less than to hang and remove it from racks, and 12.6 minutes less than to hang and remove it from the umbrella-type outdoor line.

## PURPOSE AND SCOPE OF THE STUDY

Although the automatic clothes dryer for the home laundry has been generally available for several years, only a few studies of its performance and effect on fabric properties have been published.

The work reported here was conducted to determine the effect of automatic dryers on selected fabrics ordinarily washed in the family laundry. As a basis of comparison, the effect of conventional drying methods was also investigated. To obtain quantitative data, experiments were designed to measure changes from the original in color, chemical properties, strength, and dimensions in the fabrics dried in various ways.

In addition, the effect of certain factors on the efficient use of dryers was investigated; these factors included size, composition, and moisture content of the load and special design features of the dryers. Operating and performance characteristics of dryers were also studied.

## REVIEW OF LITERATURE

In 1953 Weaver and Thomas (7)<sup>1</sup> reported that drying washed articles in dryers gave more satisfactory results than drying on an outside line in respect to the following factors: Loss of tensile strength, weight, and color except for certain

<sup>1</sup> Italic numbers in parentheses refer to Literature Cited, p. 28.

blues, retention of whiteness, and time required for handling clothes after they were washed. Shrinkage was less for line-dried than for dryer-dried clothing. Energy costs for drying 8-pound loads averaged 2.7 kilowatt hours for electrically operated dryers and 9.6 cubic feet for gas dryers.

Poole<sup>2</sup> found that when clothes were dried in automatic clothes dryers, some fading and shrinkage of decorative bands occurred in terry towels and wash cloths, but no appreciable shrinkage occurred in cotton socks; pillowcases yellowed slightly; and clear plastic buttons became distorted. In a preheated dryer the average time for drying an 8-pound load from a wringer-type machine was 52 minutes. Drying a 6-pound and a 12-pound load required practically the same time and heat energy per pound of moisture removed. However, an 8-pound load made up of 4 pounds of sheets and pillowcases and 4 pounds of towels and wash cloths required less time and heat energy per pound of moisture removed than did two 4-pound loads, one of sheets and pillowcases and the other of towels and wash cloths.

Leavitt (4) in 1954, discussing the dimensional stability of viscose-rayon, stated that shrinkage during tumble drying results from overdrying and can be remedied by removing clothes from dryer while slight moisture remains.

## DRYERS AND DRYING METHODS STUDIED

Effects of repeated drying of fabrics in automatic gas and electric dryers, on racks indoors, and on lines outside, protected and unprotected from the sun, were investigated.

In design the dryers used were representative of the types available on the market.<sup>3</sup> They included an electrically-heated cabinet-type dryer with metal rods for hanging the fabrics, and automatic tumbler-type dryers with perforated and nonperforated drums heated with gas and electricity. Both 120- and 240-volt dryers were included. Drums were of galvanized, porcelain-enameled, and synthetic-enameled metal. Timer controls were of two types—one provided a single temperature, the other selective temperatures. Controls provided drying times ranging from 1 to 3 hours. Detailed descriptions of individual dryers are given in table 1.

The electric tumbler dryers were connected to circuits with voltage controlled to within  $\pm 2$  volts by an automatic regulator. The gas dryers were

connected with pressure regulators in the gas lines. Electric and gas meters were the integrating type with scales reading to 0.01 kilowatt-hour and 0.01 cubic foot, respectively. The dryers were installed with no outside venting in a large laboratory fairly open for air circulation.

The indoor drying racks had collapsible frames with wood bars. For outdoor drying, umbrella-type racks with plastic lines were used; swatches of fabrics were hung with clothespins. One rack was completely unprotected; the other covered with a shelter that provided shade during all seasons. The drying periods extended throughout the entire year. Although some drying days were not sunny, no samples were placed outside if there was precipitation.

Outdoor racks were located approximately 1,000 feet from a coal-burning heating plant, which was provided with a precipitator for filtering the smoke. Similar conditions might exist in home drying yards.

## EXPERIMENTAL PROCEDURES

### Selecting and Preparing Fabrics for Drying

Fabrics selected for the study were of types commonly laundered in the home—sheetings, toweling, and clothing fabrics. They were obtained from manufacturers and local merchants. For each experiment each fabric purchased as yard goods was from the same bolt and sheets and terry towels were of the same brand and quality.

A total of 14 white<sup>4</sup> and 21 dyed fabrics was used in different phases of the study. Fibers in the white samples were cotton, linen, nylon, acetate, and viscose rayon. Most of the dyed materials were cotton; a few were acetate-viscose rayon.

Test fabrics were cut into swatches, varying in size from one-half to a yard square, and were marked with consecutive numbers as they were cut. To remove finishes that might affect original measurements, the samples were hemmed,

<sup>2</sup> POOLE, NADA D. USE OF DIFFERENT COMBINATIONS OF LAUNDRY APPLIANCES. DRYER AND CONVENTIONAL WASHER FOR WEEKLY FAMILY LAUNDRY. (Thesis, M. S. Iowa State College, Ames, Iowa.) 1951.

<sup>3</sup> Dryers for use in the study were obtained in the period 1951-1953.

<sup>4</sup> In this publication, white is used to denote fabrics which were purchased as white goods.

TABLE 1.—*Description of dryers<sup>1</sup>*

Code	Heat source	Type	Manufacturer's rating of energy input	Temperature controls	Maximum time setting	Vent location	Drum			Manufacturer's rating of clothes capacity
							Diam- eter	Depth	Finish	
C	Electric	Cabinet	1,250 watts	Not adjustable	3.0	Around lid	28.00	16.50	Enamelled	8 dry.
D	Electric	Tumbler	4,700 watts	Not adjustable	3.0	Top back	28.00	16.50	Nonperforated	42
E	Gas	Tumbler	19,000 B. t. u.	Not adjustable	3.0	Top back	28.00	16.50	Enamelled	18 wet.
F	Electric	Tumbler	1,450 watts	Not adjustable	3.0	Top back	28.00	16.50	Nonperforated	42
G	Electric	Tumbler	4,650 watts	Low to high	1.0	Bottom front	26.00	16.75	Galvanized	18 wet.
H	Gas	Tumbler	18,000 B. t. u.	Low, medium, high.	2.2	Bottom front	26.75	17.50	Galvanized	44
I	Electric	Tumbler	4,700 watts	Low, medium, high.	1.5	Bottom front	26.00	19.00	Perforated	9 dry.
J	Electric	Tumbler	1,750 watts	Low, medium, high.	1.5	Bottom front	26.00	19.00	Enamelled	50
										Full washer load.
										Full washer load.

<sup>1</sup> Other drying methods: A, outside line; B, inside rack.

then washed through a cycle of an automatic washer and dried on racks in the laboratory. The samples were randomized to make up the loads to be dried in different ways; loads were randomized to determine the sequence of drying methods from day to day.

In some of the tests, samples were prepared for drying by soaking in clear water; in others they were washed in a detergent solution and rinsed. Excess water was removed by spinning the load in an automatic washer; in all tests except those in which moisture content was a variable, moisture was controlled to within  $85 \pm 2$  percent of the dry weight of the load by the length of the spin. The dry weight of the load was established by taking the mean of several preliminary daily weighings of each load after the dry swatches had hung on a rack in the laboratory overnight.

The wet samples were tied in a plastic square for weighing, after which they were dried in the specified manner.

The tumbler dryers were placed on platforms equipped with hydraulic jacks which permitted raising and lowering the dryers onto a scale rolled under the platform. This device made it possible to weigh them intermittently as drying progressed to determine the dry point of a load while it was in the dryer. This procedure was used in the early stages of experimentation. After a number of dryings, a length of time for drying the load was established for each dryer and intermittent weighings were discontinued. As the number of dryings increased, all loads became lighter. Dry weights were therefore adjusted from time to time to compensate for this loss in weight.

Loads dried on outside lines and on inside racks were allowed to hang until they were dry to the touch.

After being dried, the swatches were bundled into the plastic square without being folded, weighed for determination of the exact amount of moisture removed, and placed in a cabinet drawer until the next drying.

## Evaluation Criteria

As a basis for evaluating the effects of the different drying methods on fabrics, data were obtained on changes that occurred in fabric properties during drying.

Part or all of the following measurements were made on the test fabrics before the first test drying and at intervals as reported.

*Color.*—A Hunter Color and Color-Difference Meter was used to measure the color. The Hunter instrument measured  $R_d$ , diffuse reflectance;  $a$ , redness in the plus direction and greenness in the minus; and  $b$ , yellowness in the plus direction and blueness in the minus. The overall color change,  $\Delta E$ , in the NBS unit (a measure of an average, minimum perceptually important color difference) was calculated from the change in  $R_d$ ,  $a$ , and  $b$  by the formula supplied with the instrument where:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2};$$

$\Delta L = \Delta R_d \times$  factor to determine lightness change

At least three readings were made per sample. Values of  $a$  for the white fabrics are not reported, since they contribute so small a part to the total color. The printed materials, where not all over prints, were placed on the instrument in such a manner that chiefly the background color was measured.

*Chemical degradation.*—Viscosity of nylon fabrics was measured in an *m*-cresol solution by a method similar to that of Boulton and Jackson (2, 3). A conditioned weight of nylon equivalent to 0.400 gm. dry weight was dissolved in 10 ml. *m*-cresol in a 50 ml. glass-stoppered erlenmeyer flask. With continuous shaking, solution was usually complete in 30 minutes. The solution was then transferred to a calibrated Ostwald-Fenske viscometer and the viscosity measured at 25° C. Results are expressed in centipoises.

Fluidity (reciprocal viscosity) of cotton, linen, acetate-viscose rayon, and viscose rayon fabrics was measured in cuprammonium hydroxide solution according to the specification developed by the American Society for Testing Materials—ASTM Designation: D 539-53 (1)—with the following changes: 80-mesh copper gauze was used instead of powdered copper in making up the solution and samples were dissolved in mixing vials similar to those used by Mease (5) and then transferred to the viscometers for measurement.

*Bursting strength.*—Bursting strength was measured in accordance with procedures outlined in the ASTM Designation: D 231-46 (1). Instead of cutting samples of specified size, measurements were made within the swatch and the resulting holes mended by machine. Initial bursting strength values are the means of measurements of only those swatches included in each experiment.

*Dimensional change.*—Dimensional change was

determined from the average of three 8-inch distances marked in both warp and filling directions on each sample. The effects of the different drying methods on the dimensions of the fabric are reported only for the warpwise direction. Changes in filling measurements were, in general, too small to serve as evaluation criteria.

*Visual judgments.*—Discoloration of white fabrics was determined visually by a judging panel. Before being judged, the samples were wet and rack-dried to eliminate differences in texture due to drying methods.

Samples of each fabric were presented for judging according to a randomized pattern, four at a time (one of a fabric from each drying method) under daylight controlled to give a good light without glare. Intensity of the light was measured with a Weston foot-candle meter. The four samples were displayed on a white background within an area in which differences in light intensity were no more than 10 percent. Judges arranged the samples (keeping them flat on the surface and within prescribed limits), ranked from most to least desirable, then scored them on an acceptability scale ranging from 1, very poor, not acceptable, to 5, very good, would not attempt to improve.

*Visible wear.*—Any visible wear due to drying methods was observed by the laboratory staff in the experiment in which samples were wet by soaking.

### Measurement of Temperature

Two types of temperature measurements were made—of air and of fabrics. Thermocouple junctions located in the exhaust air at the lint trap and inside the drum about 3 inches from the center of the door, protected from the tumbling load by a wire guard, measured the air temperatures. A potentiometer recorded these temperatures during the drying period. From this record the maximum temperature reached in the air at each location was obtained. Fabric strips marked with temperature-indicating crayons were attached to pieces of the load to indicate the temperatures reached by the fabric. Crayons used were designed to melt at intervals of 25 degrees.

### Analysis of Data

Analysis of variance was used to determine differences among the data collected. Where this

analysis showed significant differences, Duncan's Multiple Significance Test Method was applied to arrayed means to determine where the differences occurred. In the discussion where significant or nonsignificant differences are noted, all statements refer to the 5-percent level of probability. It is possible in some instances where statistical significances exist, that practical differences may not be present.

## EFFECT OF DRYING ON FABRICS

### White Fabrics

The 14 white fabrics used in the study included 8 cottons—broadcloth, muslin, dress percale, sheeting percale, denim, huck, terry, and jersey. The other 6 were dress-weight and towel linen, nylon crepe and tricot, acetate-viscose rayon crepe, and viscose rayon crepe.

In the first phase of the study the fabrics were wet for drying by soaking them in clear water. In a second series of experiments they were washed in a detergent solution between dryings.

### Fabrics Soaked Between Dryings

All of the white fabrics were used in tests in which samples were prepared for drying by soaking only. Each was dried in the following 10 ways: On outdoor lines (60 out of 100 dryings were on sunny days, September through March), on racks indoors, in an electrically heated cabinet, in an electric nonperforated-drum tumbler dryer with single thermostat setting, and in a gas and an electric perforated-drum tumbler operated at each of three thermostat settings.

An 8-pound load, including 2 swatches of each fabric, was prepared for drying by each method. Each load was soaked for 3 minutes in warm water (approximately 100° F.); then excess water was removed and the samples were weighed according to the general procedures previously described (p. 7).

After the fabrics had been dried 50 times by the different methods, measurements were made to determine changes from the original in color, dimensions, and bursting strength. After 100 dryings, measurements of chemical degradation were also made. Where visible wear was noted, it was recorded.

*Color.*—Changes in reflectance,  $R_d$ , are shown in table 2.

TABLE 2.—*Initial  $R_d$ <sup>1</sup> and  $R_d$  loss<sup>2</sup> in 14 white fabrics dried under different conditions after being soaked in clear water*

Drying condition	Broad-cloth	Cotton				Initial $R_d$	Linen	Nylon	Acetate-viscose rayon crepe	Viscose rayon crepe
		Denim	Huck	Jersey	Muslin					
	86.9	83.6	86.1	87.1	86.9	86.1	87.5	85.8	86.3	72.2
Loss after 50 dryings										
A. Outside line, unprotected										
from sun	5.1	6.6	9.6	11.5	6.0	6.1	5.2	12.7	6.6	4.3
Inside rack	1.0	1.8	2.7	2.2	1.3	1.3	1.5	3.3	1.7	1.0
Electric cabinet	1.2	1.8	2.8	1.9	1.3	1.1	1.5	2.7	2.5	1.7
Electric tumbler	5.0	6.0	7.7	6.5	6.4	4.8	5.7	7.2	6.0	4.6
Electric tumbler:										
High heat	4.3	5.0	5.9	4.9	4.7	3.5	4.9	5.4	5.6	3.5
Medium heat	4.0	4.4	6.1	4.6	4.9	3.5	4.7	5.3	5.5	4.1
Low heat	4.8	5.1	6.7	5.7	5.5	3.9	5.3	6.0	6.0	3.7
H. Gas tumbler:										
High heat	3.1	4.0	6.2	4.0	3.7	2.7	3.5	5.2	5.7	4.2
Medium heat	2.7	3.5	5.7	4.5	3.6	3.2	3.4	5.8	5.4	3.6
Low heat	2.8	4.4	6.4	5.2	3.9	2.9	3.9	6.3	5.3	3.6
Loss after 100 dryings										
A. Outside line, unprotected										
from sun	10.0	13.6	16.8	19.8	11.7	12.0	10.7	20.7	11.5	9.2
Inside rack	2.2	3.0	4.8	3.8	2.4	2.3	2.4	4.2	2.6	1.9
Electric cabinet	1.7	2.3	4.4	3.4	2.0	1.9	2.3	3.9	2.2	3.6
D. Electric tumbler	7.5	8.8	11.2	10.2	9.9	8.0	9.6	10.5	8.5	7.0
G. Electric tumbler:										
High heat	6.4	7.2	8.5	7.2	5.9	7.8	7.2	7.7	6.1	4.6
Medium heat	6.1	7.1	9.1	8.3	7.9	6.2	7.7	7.6	6.4	5.5
Low heat	7.3	7.8	9.7	9.6	8.5	6.7	8.7	9.3	8.0	5.6
H. Gas tumbler:										
High heat	4.0	5.1	8.5	6.0	5.8	4.1	5.6	6.4	5.1	4.2
Medium heat	4.2	4.7	7.6	6.0	5.6	4.7	5.6	6.9	5.4	4.5
Low heat	4.6	6.1	8.5	7.5	6.6	5.2	6.9	7.6	6.0	5.0

<sup>1</sup> Diffuse reflectance, measured with Hunter Color and Color-Difference Meter; MgO white = 100.0.

<sup>2</sup> Reflectance loss indicates graying.

In fabrics dried 50 times, all methods of drying produced graying as indicated by a decrease in  $R_d$  of 0.9 unit or more. The electrically heated cabinet dryer and the rack in the laboratory produced the least graying. Outdoor drying caused the greatest decrease in reflectance in all but 4 fabrics; in 1 the decrease was as much as 12.7 points.

After 100 dryings, while the results showed a change in magnitude, they were in much the same relation as after 50 dryings, except that all fabrics were more gray in outside drying than in other methods; for most fabrics the change was less for those dried in the gas dryer than in the electric one.

Changes in yellowness-blueness,  $b$ , are shown in table 3. With 50 dryings, all methods produced an increase in yellowness in all fabrics except denim. Denim, which was not completely bleached when new, lost yellow in all 10 drying methods. Inside rack and outside drying caused the least or next to the least yellowing in the most fabrics. The gas dryer on all three settings caused significantly more yellowing than any other drying method in 10 of the fabrics. In the 3 electric dryers, fabrics dried in the cabinet generally yellowed less than those in the tumblers.

With 100 dryings, inside rack and outside drying brought about the least or next to the least yellowing in 12 of the fabrics. The gas dryer caused significantly more yellowing in 10 of them. Effects of the electric dryers fell between those cited. Except in 1 fabric, the cabinet electric dryer, when significantly different, caused less yellowing than the other electric dryers.

*Chemical degradation.*—After 100 dryings little chemical damage was found in cotton, linen, viscose, and acetate-viscose fabrics that had been dried on an indoor rack or in gas or electric dryers (table 4). Outdoor drying caused considerably greater degradation in these fabrics. The gas dryer caused about the same degree of chemical damage as outdoor drying in the two nylon fabrics, while drying on an indoor rack or in electric dryers caused little or no damage.

*Bursting strength.*—With 50 dryings none of the methods caused a significantly different loss in strength in cotton huck, jersey, muslin and terry, and acetate-viscose rayon crepe (table 5). The inside rack and the electrically heated cabinet dryer brought about the least or were in the group of methods bringing about the least loss of strength in 8 of the remaining 9 fabrics. Of the other

drying methods, no one stood out as causing the greatest loss in strength.

With 100 dryings, the indoor rack and the electric cabinet caused the least loss of strength or were in the group of methods causing the least loss in 13 and 10 fabrics, respectively (table 5). Drying outdoors brought about the greatest loss or was in the group causing the greatest loss in strength in 12 fabrics. Losses of strength from the tumbler drying methods tended to fall within groups without significant differences, with the exception of the adverse effect of gas dryers on nylon.

*Dimensional change.*—The effects of the different drying methods on the warpwise dimension of the fabrics after 100 dryings are shown in table 6. Tumbler drying caused more shrinkage than did any other method in the linens and all the cotton fabrics except jersey, which stretched in all drying methods. Changes in the tumbler-dried fabric ranged from 0.6 to 3.7 percent for linens and from 2.2 to 7.6 percent for cottons.

Acetate-viscose rayon crepe exhibited the greatest shrinkage of any of the woven fabrics, ranging from 8.5 to 15.7 percent; shrinkage in this fabric was least from the gas-heated dryer and greatest from the electrics. The change in the nylon fabrics in every instance was less than 1 percent.

In all the fabrics most of the change had occurred by the end of 50 dryings.

*Visible wear.*—After the fabrics had been dried 100 times, swatches dried on an inside rack and in the electric cabinet dryer showed no visible wear and those dried on outside lines showed only clothespin damage, while certain swatches from the tumbler dryers were noticeably damaged. The damage was concentrated almost entirely near the outer edges, on the turned hems, and in lengthwise creases that developed during repeated dryings in the tumbler dryer. Creasing was especially evident in the linen toweling, which acquired lengthwise folds that wore threadbare. Dress linen was worn at the hems and small holes developed in the creased areas. Crisp cottons—broadcloth, muslin, dress percale, and sheeting percale—showed the greatest wear from tumbling; soft cottons—denim, jersey, and terry—were much less worn. Nylon, acetate-viscose rayon and viscose rayon crepes were slightly damaged; nylon tricot showed no wear.

The damage on creases and folds might have been eliminated had the swatches been washed and pressed between dryings. This treatment, however, would not eliminate the wear on hems.

TABLE 3.—Initial  $b^1$  and  $b$  change $^2$  of 14 white fabrics dried under different conditions after being soaked in clear water

<sup>1</sup> yellowness in plus direction, blueness in minus direction; measured with

## Hunter Color and Color-Difference Meter.

2 Yellow-blue change: Toward yellow in plus direction toward blue in

1 snow-blue change; toward yellow in plus minus direction. 3 Not completely bleached

Note.—Data for a fabric after 50 or 100 dryings marked with the same superscript were not significantly different at the 5-percent level of probability.

TABLE 4.—*Initial and final fluidity or viscosity of 14 white fabrics dried 100 times under different conditions after being soaked in clear water*

Drying condition		Fluidity						Viscosity		
		Cotton			Linen			Viscose rayon crepe		Nylon
Broad-cloth	Denim	Huck	Jersey	Muslin	Pereale, 80-square	Percal, sheeting	Terry	Dress weight	Crash toweling	Crepe
R <sub>hes</sub>	R <sub>hes</sub>	R <sub>hes</sub>	R <sub>hes</sub>	R <sub>hes</sub>	R <sub>hes</sub>	R <sub>hes</sub>	R <sub>hes</sub>	R <sub>hes</sub>	R <sub>hes</sub>	C <sub>p</sub>
6.7	8.0	5.9	4.0	7.5	4.0	7.0	6.2	19.1	7.3	15.5
Initial										
After 100 dryings										
A. Outside line, unprotected										
from sun	11.5	13.2	10.8	8.4	12.6	9.0	11.0	22.4	11.4	18.1
B. Inside rack	8.1 <sup>e</sup>	8.7 <sup>ab</sup>	7.0 <sup>a</sup>	5.2 <sup>ed</sup>	7.8 <sup>d</sup>	5.4 <sup>b</sup>	7.3 <sup>a</sup>	20.4 <sup>b</sup>	8.6 <sup>ab</sup>	15.5 <sup>bcd</sup>
C. Electric cabinet	8.0 <sup>e</sup>	8.7 <sup>ab</sup>	7.0 <sup>a</sup>	5.4 <sup>be</sup>	8.1 <sup>d</sup>	5.6 <sup>b</sup>	7.7 <sup>e</sup>	19.8 <sup>d</sup>	8.7 <sup>a</sup>	16.0 <sup>ab</sup>
D. Electric tumbler	8.3 <sup>de</sup>	8.5 <sup>b</sup>	6.9 <sup>a</sup>	5.1 <sup>cd</sup>	8.4 <sup>ed</sup>	5.4 <sup>b</sup>	7.7 <sup>e</sup>	6.7 <sup>b</sup>	20.2 <sup>b</sup>	7.3 <sup>de</sup>
E. Electric tumbler:										
High heat	9.3 <sup>ab</sup>	10.1 <sup>a</sup>	7.2 <sup>a</sup>	5.8 <sup>a</sup>	9.6 <sup>a</sup>	6.8 <sup>a</sup>	9.4 <sup>ab</sup>	7.2 <sup>a</sup>	21.1 <sup>a</sup>	8.2 <sup>ab</sup>
Medium heat	8.9 <sup>bo</sup>	9.6 <sup>ab</sup>	7.8 <sup>a</sup>	5.6 <sup>ab</sup>	9.1 <sup>ab</sup>	6.4 <sup>a</sup>	9.8 <sup>a</sup>	7.2 <sup>a</sup>	20.2 <sup>be</sup>	8.3 <sup>ab</sup>
Low heat	8.9 <sup>bo</sup>	10.0 <sup>ab</sup>	7.4 <sup>a</sup>	5.6 <sup>ab</sup>	8.9 <sup>bo</sup>	6.3 <sup>a</sup>	9.8 <sup>a</sup>	7.1 <sup>a</sup>	19.9 <sup>cd</sup>	8.1 <sup>bo</sup>
F. Gas tumbler:										
High heat	9.4 <sup>a</sup>	9.5 <sup>ab</sup>	7.6 <sup>a</sup>	5.6 <sup>ab</sup>	9.1 <sup>ab</sup>	6.7 <sup>a</sup>	9.3 <sup>ab</sup>	7.3 <sup>a</sup>	21.1 <sup>a</sup>	7.8 <sup>cd</sup>
Medium heat	8.7 <sup>ed</sup>	9.2 <sup>ab</sup>	6.9 <sup>a</sup>	4.9 <sup>a</sup>	8.9 <sup>bo</sup>	5.7 <sup>b</sup>	8.5 <sup>be</sup>	6.7 <sup>b</sup>	19.6 <sup>d</sup>	7.2 <sup>e</sup>
Low heat	9.0 <sup>bo</sup>	8.8 <sup>ab</sup>	7.0 <sup>a</sup>	4.9 <sup>a</sup>	8.1 <sup>d</sup>	5.6 <sup>b</sup>	8.7 <sup>ab</sup>	6.7 <sup>b</sup>	20.2 <sup>bo</sup>	7.2 <sup>e</sup>

NOTE.—Data for a fabric marked with same superscript were not significantly different at the 5-percent level of probability.

TABLE 5.—Initial and final bursting strength of 14 white fabrics dried 50 and 100 times under different conditions after being soaked in clear water

**NOTE.**—Data for a fabric after 50 or 100 dryings marked with the same superscript were not significantly different at the 5 percent level of probability.

TABLE 6.—*Dimensional change (warpwise) in 1/4 white fabrics dried 100 times under different conditions after being soaked in clear water*

Drying condition	Cotton						Linen			Nylon			Acetate-viscose rayon crepe		Percent
	Broad-cloth	Denim	Huck	Jersey	Muslin	Percal, 80-square	Percal, 80-square	Percal, sheeting	Terry	Dress weight	Crash-toweling	Crepe	Tricot		
A. Outside line, unprotected from sun	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
sun	-1.6	-1.6	-2.9	+18.0	-1.3	-2.0	-1.5	+0.4	-0.2	-0.6	+0.1	0	-9.7	+1.6	
B. Inside rack	-	-	-1.2	-2.0	+13.0	-1.0	-1.2	-	.6	+1.3	0	+.8	-9.8	+1.3	
C. Electric cabinet	-	-	-1.1	-1.8	+10.3	-1.1	-1.4	-	1.2	+1.7	0	+.4	-11.8	-.4	
D. Electric tumbler	-	-	-3.3	-3.8	-6.8	+8.2	-3.2	-	2.5	-4.0	-.8	-.8	-14.0	-1.8	
G. Electric tumbler:															
High heat	-3.7	-4.4	-6.4	+7.0	-2.9	-3.6	-2.8	-	4.0	-1.0	-.2	0	-15.7	-1.6	
Medium heat	-3.6	-4.6	-5.8	+3.8	-3.2	-3.4	-2.2	-	4.0	-1.4	0	0	-14.9	-2.1	
Low heat	-3.8	-4.6	-6.8	+2.8	-3.4	-3.9	-2.4	-	4.5	-.8	-.1	+.7	-15.4	-1.6	
H. Gas tumbler:															
High heat	-2.8	-3.9	-5.8	+2.8	-2.7	-2.9	-2.2	-	4.2	-.6	-2.2	0	+.4	-9.0	
Medium heat	-2.8	-3.4	-6.2	+6.8	-2.8	-2.9	-2.4	-	4.2	-.6	-2.6	-.1	+.3	-8.5	
Low heat	-3.2	-4.1	-7.6	+5.8	-2.9	-3.4	-2.6	-	3.7	-.8	-2.8	+.1	+.1	-9.4	

## Fabrics Washed Between Dryings

Since the white fabrics dried repeatedly after only a clear-water soaking were considerably yellowed and grayed from some of the drying methods, an investigation was made to determine the effect of washing between dryings on some of the fabric properties. This experiment was conducted from February through September of one year.

Four drying conditions were chosen that represented the range of effects on the fabrics: An outside line, a gas dryer, an electric dryer, and an inside rack.

Five white fabrics representative of those in the former experiment were selected: Cotton jersey, percale sheeting, and terry; nylon tricot; and acetate-viscose rayon crepe.

Samples of the fabrics were washed together in an automatic washer for 5 minutes in a 0.1-percent detergent solution at 140° F., and rinsed in the two automatic rinses at 100°, provided by the washer. The moisture content was controlled to within  $85 \pm 2$  percent of the dry weight of the load. Squares of bleached cotton material were wet to the same moisture content and added to the test materials to make the dryer load 8 pounds, dry weight.

After the fabrics had been washed and dried 50 times, color and bursting strength measurements were made to evaluate effects of the treatments, and four judges appraised the appearance of the washed samples. The detergent used contained a brightener; measurements made included the contribution of fluorescence.

Data for these washed samples and similar data from the experiment in which the samples were only soaked are given in table 7.

**Color.**—The buildup of graying which occurred in the 50 dryings without washing, especially on samples dried on the outside line, was lessened, although not completely eliminated, by washing, and the outside line assumed a more favorable position among the drying methods.

The yellowing that developed in the cottons in the tumbler dryers when the fabrics were only soaked was decreased and differences between effects of the four drying methods were made smaller by washing. The relationship of the drying methods was the same for nylon tricot and acetate-viscose rayon crepe whether washed or only soaked, but washing did not generally decrease the yellowing.

Judges' scores for washed samples given in table

7 followed more closely changes in *b* than in *R<sub>d</sub>*; samples that had grayed and yellowed were judged less acceptable in appearance than those that had grayed but not yellowed. Cotton jersey dried in the gas drier compared with acetate-viscose rayon crepe dried indoors shows this distinction.

It should be noted that any measured change in color makes the same contribution to total color change whether or not it is desirable to the appearance of the fabric. (See formula, page 7.) Therefore, reporting of  $\Delta E$  in white fabrics, unless all have changed in like direction, has little meaning; as a result, no  $\Delta E$  data have been included for the white fabrics.

**Bursting strength.**—In considering the bursting-strength figures in table 7, only the relationship of the methods should be compared, since the materials were not all from the same yardage. Measurements of both the washed and soaked samples did not show superiority of any one drying method over the others.

Since washing improved much of the graying and yellowing encountered in the experiment in which the materials were only soaked, washing was incorporated as a regular part of the procedure in the remainder of the study.

## Dyed Fabrics

The effect of drying methods on the color of dyed fabrics is always of concern to the home-maker. Few quantitative data on changes resulting from different methods of drying have been reported in the literature. Weaver and Thomas (7) found considerable fading of dyed fabrics dried outside, especially in the red dyes, in contrast to little or no change in dyed fabrics dried in the gas or electric dryer.

The phase of the study reported here was made primarily to determine quantitative color changes in selected dyed fabrics dried by the following home methods: Outside line unprotected from the sun, outside line in the shade, electrically heated tumbler dryers D and I, and gas-heated tumbler dryers E and H. (See table 1.) Bursting strength and dimensional changes were also determined.

Two of the four tumbler dryers used, a gas and an electric, had nonperforated enameled sheet-metal drums and single temperature thermostats; another had a perforated galvanized drum; the fourth had a perforated porcelain-enamedled drum. The last two were operated on high temperature

TABLE 7.—Effects of 50 dryings by 4 methods<sup>1</sup> on 5 white fabrics washed in a detergent solution and soaked in clear water between dryings, arranged poorest to best

Cotton jersey		Cotton percale sheeting			Cotton terry			Nylon tricot			Acetate-viscose rayon crepe		
Drying method	Washed	Drying method	Washed	Drying method	Soaked	Drying method	Washed	Drying method	Soaked	Drying method	Washed	Drying method	Soaked
I	-2.7	O	-11.5	G	-2.9	E	-5.7	G	-0.4	O	-12.7	O	-0.8
G	-2.4	E	-6.5	I	-2.1	O	-5.2	G	-1	E	-7.2	G	-1.1
E	-2.2	G	-5.2	O	-2.1	G	-3.9	O	+.4	I	-6.3	I	+.4
O	-2.2	I	-2.2	E	-1.7	I	-1.5	I	+.6	I	-3.3	E	+.8
R <sub>d</sub> change <sup>2</sup>													
b change <sup>3</sup>													
O	-1.7	G	+4.7	O	-2.2	G	+1.5	O	-3.7	G	+5.9	G	+4.5
I	-2.1 <sup>a</sup>	E	+2.0	G	-2.7 <sup>a</sup>	E	+1.2	I	-4.5 <sup>b</sup>	E	+1.9	E	+2.3
G	-2.1 <sup>a</sup>	O	+1.6 <sup>a</sup>	E	-2.7 <sup>a</sup>	O	+.8	E	-5.2 <sup>ab</sup>	I	+1.4	O	+1.7 <sup>a</sup>
E	-2.3 <sup>a</sup>	I	+1.4 <sup>a</sup>	I	-2.7 <sup>a</sup>	I	+.5	G	-5.4 <sup>a</sup>	O	+1.2 <sup>a</sup>	I	+1.5 <sup>a</sup>
Judges' average scores <sup>4</sup>													
G	4.5	—	—	O	4.6	—	—	O	4.8	—	—	G	2.4
O	4.8	—	—	G	4.9	—	—	I	4.8	—	—	E	3.4
E	4.8	—	—	E	4.9	—	—	E	5.0	—	—	O	3.8
I	4.8	—	—	I	5.0	—	—	G	5.0	—	—	I	3.9
Bursting strength <sup>5</sup>													
O	88.7 <sup>a</sup>	O	77.2 <sup>a</sup>	O	147.2	O	154.4 <sup>a</sup>	O	116.4 <sup>a</sup>	E	154.9 <sup>a</sup>	O	137.9
G	89.3 <sup>a</sup>	G	78.4 <sup>a</sup>	E	161.4 <sup>a</sup>	G	156.0 <sup>a</sup>	I	123.7 <sup>a</sup>	O	157.9 <sup>a</sup>	G	159.9 <sup>a</sup>
I	89.8 <sup>a</sup>	E	80.5 <sup>a</sup>	I	169.3 <sup>a</sup>	E	158.7 <sup>ab</sup>	E	123.7 <sup>a</sup>	G	158.3 <sup>a</sup>	E	163.1 <sup>ab</sup>
E	91.1 <sup>a</sup>	I	83.4 <sup>a</sup>	G	169.8 <sup>a</sup>	I	165.8 <sup>b</sup>	G	124.1 <sup>a</sup>	I	165.4 <sup>a</sup>	I	151.1 <sup>a</sup>
G													
O	125.4	O	137.9	G	66.4	O	69.8 <sup>a</sup>	E	68.3 <sup>b</sup>	G	70.5 <sup>a</sup>	O	69.8 <sup>a</sup>
G	150.3 <sup>a</sup>	G	68.3 <sup>b</sup>	E	69.6 <sup>ab</sup>	E	72.2 <sup>a</sup>	I	70.9 <sup>a</sup>	E	73.2 <sup>a</sup>	G	70.9 <sup>a</sup>
I	163.1 <sup>ab</sup>	O	70.9 <sup>a</sup>	I	165.1 <sup>a</sup>	I	165.1 <sup>a</sup>	I	165.1 <sup>a</sup>	I	165.1 <sup>a</sup>	I	165.1 <sup>a</sup>

Note.—Data for a fabric marked with the same superscript within a group of 4 were not significantly different at the 5-percent level of probability. Only the b changes and bursting-strength data were analyzed.

<sup>1</sup> Drying methods: E—Electric tumbler.

<sup>2</sup> Reflectance change: Lighter in plus direction, darker in minus direction.

<sup>3</sup> Yellow-blue change: Toward yellow in plus direction, toward blue in minus direction.

<sup>4</sup> Scale for scoring: 1. Very poor (not acceptable).  
2. Poor (barely acceptable).

3. Fair (could be considerably improved).

4. Good (acceptable, but would like to improve it).

5. Very good (would not attempt to improve it).

Data are averages of the scores of 4 judges.  
<sup>6</sup> Only the relationship of the drying methods should be considered; materials were not all from the same yardage.

settings. The experiment was conducted from January to August of one year.

The following dyed fabrics were selected for the study:

Cotton broadcloth—coral, light blue, and green  
chambray—green and yellow  
percale prints—predominating colors, purple, red, blue, and green  
plisse prints—pink and blue backgrounds  
sheeting—pink and blue  
terry towels—yellow, rose, light blue, green, and pink

Acetate-viscose rayon crepe—medium blue, rose, and violet

ASTM classifications by a launderometer and a fadeometer and manufacturers' information are given in table 8. The fadeometer did not predict the performance of the fabrics in the drying methods studied.

Terry was purchased as towels and sheeting as sheets; the other fabrics were purchased by the yard from one bolt. All but the towels were cut into swatches of approximately 18 by 36 inches.

To remove excess dye and sizing, fabrics were sorted and washed separately according to color. Areas to be measured for dimensional change or for color readings were marked with ink or with stitching, and the fabrics were again washed to remove soil of handling. Color readings were made; the samples were then conditioned in an atmosphere of controlled humidity and temperature, and dimensional and bursting strength measurements were made. Two samples of each fabric and color were randomly assigned to each test load.

In preparation for dryings, test loads were washed in an automatic washer for 5 minutes in a 0.05-percent solution of detergent at 120° F. and rinsed twice in water at 100°.

Loads were dried in random order, with the exception that those dried outside were hung in the morning so they could be put away by the end of the day. Between dryings unfolded swatches were bundled together and tied into plastic squares, in which they were held until they were used again. In the dryers loads were dried to a predetermined weight.

After each of the 6 loads had been dried 50 times,  $R_d$ ,  $a$ , and  $b$  were measured with the Hunter Color and Color-Difference Meter and compared with the original readings (table 9).

Data are arranged in this table by groups of fabrics similarly affected by drying methods.

*Total color change.*—Since 1 NBS unit is considered a perceptually important color change, a difference of less than 1 between the color changes for 2 drying methods would indicate no appreciable difference in their effects. For 4 of the 21 fabrics the differences in  $\Delta E$  resulting from various drying methods were in general not enough for importance when evaluated by this criterion. For green percale print there was less than 1 unit difference in  $\Delta E$  between any 2 methods. No single method of drying blue percale print, green broadcloth, and pink sheeting produced an effect as much as 1 unit greater than every other method, although in some instances there was more than 1 unit difference between 1 method and another.

In 10 of the remaining 17 fabrics, sun drying brought about a  $\Delta E$  perceptually different from that caused by the other 5 methods. These changes were chiefly made up of a loss of the predominant color, accompanied by a large gain in reflectance, except in purple percale print where the reflectance increase was accompanied by an increase in red and in blue (probably as some of the print colors changed), and in yellow chambray where the change was mainly loss of yellow.

In those fabrics most changed by the sun, shade drying or drying in electric dryer I brought about changes next in magnitude. In general, the changes, except those caused by the sun, were not of such magnitude as to set any method apart as being different from the others.

In both gas dryers, five fabrics predominantly blue showed more color change than when dried by the other methods. All lost blue and gained reflectance, with substantial increases of green in blue broadcloth.

Gas dryer H caused the greatest change in the violet acetate-viscose rayon crepe. Loss of blue from this fabric was greater from the gas dryer than from outside drying, but outside drying caused a greater increase in reflectance.

Electric dryer I caused the greatest change in yellow terry, owing chiefly to losses of yellow and reflectance.

The effects observed here in the gas dryers are probably similar to those that prompted a study by the American Association of Textile Chemists and Colorists (6) of the destructive action of home

gas-fired dryers on certain dyestuffs. These researchers singled out oxides of nitrogen as the likely causative factor and reported that the result was not confined to any group of dyestuffs.

*Bursting strength and dimensional change.—*

Bursting-strength measurements showed no differences between methods after 50 dryings. Changes in dimensions were similar to those reported for white fabrics, where tumbling caused the most and hanging the least warp-wise shrinkage.

TABLE 8.—ASTM classification and manufacturers' information on 21 dyed fabrics

Fabric and color	Classification <sup>1</sup> by—		Information from manufacturers
	Launderometer (wash fastness)	Fadeometer (light fastness)	
<b>SOLID COLORS</b>			
Acetate-viscose rayon crepe:			
Blue	Fast to laundering without bleach.	Class 4 Class 5 Class 4	Disperse dye, with inhibitor; hand-washable.
Rose			
Violet			
Cotton broadcloth:			
Blue	Class 4	Class 5	Vat dye.
Coral	Class 3	Class 4	Azoic dye.
Green	Class 4	Class 6	Vat dye.
Cotton chambray, dress weight:			
Green	Class 4	Class 5	Vat dye.
Yellow	Class 4	Class 5	
Cotton sheeting:			
Blue	Class 4	Class 5	Vat dye.
Pink	Class 4	Class 5	
Cotton terry toweling:			
Blue	Class 4	Class 7	
Green	Class 4	Class 4	
Pink	Class 4	Class 4	Vat dye.
Rose	Class 4	Class 6	
Yellow	Class 4	Class 6	
<b>PATTERNED COLORS</b>			
Cotton percale:			
Blue	Class 4	Class 7	Resin-bonded pigment—blue ground, green, yellow; azoic dye—red.
Green	Class 4	Class 7	Vat dye—green ground; small white dots.
Red	Class 4	Class 6	Azoic dye—red ground; resin-bonded pigment—blue, green, yellow.
Purple	Class 4	Class 4	Azoic dye—purple ground, red; resin-bonded pigment—blue green.
Cotton plisse:			
Blue	Class 4	Class 8	Vat dye—blue ground; azoic dye—red, pink; resin-bonded pigment—blue, green.
Pink	Class 4	Class 6	Vat dye—pink ground; azoic dye—scarlet, wine; resin-bonded pigment—blue, chartreuse.

<sup>1</sup> Wash fastness: Cottons, ASTM Designation: D 435-42, classes 1-4; acetate-viscose rayon, D 436-37 (1).

Light fastness: ASTM Designation: D 506-55, classes 1-8 (1). In both classifications the largest number indicates the best class.

TABLE 9.—*Initial and final color readings and total color changes of fabrics dried 50 times after being washed in a detergent solution*

Drying condition		<i>R<sub>d</sub><sup>1</sup></i>	<i>a<sup>2</sup></i>	<i>b<sup>3</sup></i>	$\Delta E^4$	<i>R<sub>d</sub></i>	<i>a</i>	<i>b</i>	$\Delta E$	<i>R<sub>d</sub></i>	<i>a</i>	<i>b</i>	$\Delta E$	<i>R<sub>d</sub></i>	<i>a</i>	<i>b</i>	$\Delta E$
Fabrics in which there was little difference in color change among drying methods																	
Blue cotton percale print																	
Green cotton percale print																	
Green cotton broadcloth																	
Pink cotton sheeting																	
A. Outside line: <sup>5</sup>		15.1	-3.3	-16.9	-----	41.9	-21.2	+0.2	-----	25.4	-26.1	-0.6	-----	62.6	+17.9	+4.1	-----
Unprotected from sun		18.0	-3.6	-15.8	3.7	47.1	-20.0	0	3.5	27.0	-25.6	-.5	1.5	63.8	+13.8	+3.2	4.4
Protected from sun		17.7	-3.8	-15.7	3.6	46.6	-19.5	0	3.3	27.1	-25.9	-.4	1.5	62.4	+14.8	+3.2	3.4
D. Electric tumbler		17.7	-3.7	-16.0	2.9	45.5	-19.0	-.2	3.1	26.2	-26.4	-.4	.9	61.0	+14.5	+2.5	3.7
E. Gas tumbler		17.0	-3.8	-14.9	2.9	45.0	-19.3	0	2.7	26.0	-24.2	-1.4	2.2	60.9	+14.9	+2.8	3.3
H. Gas tumbler, high heat		16.3	-4.6	-13.8	3.8	44.4	-19.4	0	2.6	26.6	-25.9	-.1	.9	60.8	+14.9	+2.9	3.7
I. Electric tumbler, high heat		16.0	-4.3	-13.0	4.3	43.4	-18.5	0	2.8	27.6	-27.5	+.6	2.5	61.0	+13.6	+2.0	4.7
Fabrics in which sun drying brought about the most color change																	
Coral cotton broadcloth		Green cotton chambray				Green cotton terry				Pink cotton plisse print				Pink cotton sheeting			
A. Outside line: <sup>5</sup>		24.8	+44.8	+21.5	-----	45.4	-22.0	+14.2	-----	56.9	-17.4	-1.0	-----	57.4	+17.3	+1.8	-----
Unprotected from sun		32.6	+37.3	+17.2	10.7	51.2	-15.5	+9.5	8.8	60.4	-13.6	-2.8	4.6	62.0	+13.4	+2.3	4.6
Protected from sun		27.4	+43.0	+20.2	3.1	48.2	-18.2	+14.0	4.2	59.1	-14.2	-1.6	3.4	60.7	+14.2	+1.9	3.6
D. Electric tumbler		25.3	+43.2	+20.6	2.0	45.6	-20.0	+14.0	2.2	57.4	-16.0	-1.3	1.2	59.8	+14.9	+1.4	2.9
E. Gas tumbler		25.0	+42.5	+20.2	2.6	45.8	-20.2	+14.0	1.8	57.7	-16.1	-.6	1.6	59.7	+14.9	+1.6	2.7
H. Gas tumbler, high heat		26.1	+42.7	+20.8	2.3	46.1	-20.8	+14.7	1.5	59.2	-15.8	-1.7	1.7	60.0	+15.1	+1.8	2.5
I. Electric tumbler, high heat		25.4	+41.1	+20.4	3.7	45.6	-19.9	+14.8	2.1	57.4	-15.6	-1.4	2.7	59.4	+15.0	+1.4	2.6

See footnotes at end of table.

TABLE 9.—*Initial and final color readings and total color changes of fabrics dried 50 times after being washed in a detergent solution—Con.*

Drying condition	$R_a^1$	$\alpha^2$	$b^3$	$\Delta E^4$	$R_d$	$a$	$b$	$\Delta E$	$R_d$	$a$	$b$	$\Delta E$	$R_d$	$a$	$b$	$\Delta E$	
Fabrics in which sun drying brought about the most color change—Continued																	
	Pink cotton terry	Purple cotton percale print															
A. Outside line: <sup>5</sup>																	
Unprotected from sun	64.8	+18.9	+6.6	-----	10.5	+7.5	-14.4	-----	18.6	+42.1	+20.9	-----	48.3	+19.3	+9.2	-----	
Protected from sun	67.0	+12.9	+5.4	0.2	18.4	+9.6	-18.1	13.2	24.4	+30.7	+17.6	12.3	61.2	+12.1	+4.3	11.8	
D. Electric tumbler	65.7	+14.8	+5.2	4.4	13.8	+9.4	-17.0	6.0	22.0	+34.8	+19.1	8.4	59.6	+14.0	+4.6	9.8	
E. Gas tumbler	63.1	+16.0	+4.0	4.0	11.3	+8.2	-16.2	2.3	20.8	+36.5	+18.7	7.1	57.5	+13.8	+5.8	8.4	
H. Gas tumbler, high heat	62.8	+16.5	+4.4	3.8	11.4	+8.2	-15.8	2.5	21.0	+35.3	+18.5	8.3	57.4	+13.1	+8.4	8.4	
I. Electric tumbler, high heat	63.1	+17.0	+4.2	2.9	12.6	+8.0	-16.3	3.7	20.8	+34.9	+18.5	8.2	57.4	+12.4	+8.9	8.7	
	61.0	+18.0	+2.6	5.0	12.0	+7.6	-16.6	3.5	20.4	+35.1	+18.2	8.2	54.2	+13.8	+3.9	8.4	
	Rose cotton terry																
A. Outside line: <sup>6</sup>																	
Unprotected from sun	25.6	+47.1	+8.7	-----					59.6	+0.6	+35.7	-----					
Protected from sun	28.1	+42.4	+7.6	5.5	57.8	+3.1	+28.2	7.9									
D. Electric tumbler	27.5	+43.7	+7.4	3.6	58.1	+2.8	+33.0	3.9									
E. Gas tumbler	26.0	+44.5	+7.4	3.0	57.8	+2.6	+33.9	2.8									
H. Gas tumbler, high heat	26.3	+44.5	+7.3	3.0	57.5	+2.5	+33.9	2.9									
I. Electric tumbler, high heat	25.7	+45.1	+7.4	2.5	57.9	+2.3	+34.0	2.5									
	25.3	+43.6	+6.6	3.9	56.1	+2.8	+32.7	4.1									

Fabrics in which a tumbler method brought about the most color change

		Blue acetate-viscose rayon crepe						Blue cotton broadcloth						Blue cotton plisse print						Blue cotton sheeting					
A.	Outside line: <sup>6</sup>	38.6	-3.2	-18.7	-	-	-	22.8	+1.0	-36.9	-	-	-	48.9	-3.4	-13.6	-	-	-	53.5	-5.3	-13.0	-	-	-
A.	Unprotected from sun	58.4	+0.4	-7.5	17.1	24.2	+	6	-33.9	3.2	51.9	-	.9	-	-13.3	3.0	54.3	-2.8	-	-13.1	2.8	-	-	-	-
A.	Protected from sun	56.8	0	-7.6	16.8	24.4	+	1.0	-34.3	2.7	51.4	-	.9	-	-13.2	3.1	54.2	-2.8	-	-13.3	2.4	-	-	-	-
D.	Electric tumbler	53.7	-6	-5.8	16.4	23.4	0	-	-32.4	4.7	52.0	-	1.6	-	-12.8	2.6	54.4	-3.7	-	-12.0	1.8	-	-	-	-
E.	Gas tumbler	54.8	-1.8	-1.8	19.8	33.9	-7.0	-	-4.0	34.8	59.2	-	1.6	-	-2.8	13.0	61.1	-4.6	-	-2.7	11.6	-	-	-	-
H.	Gas tumbler, high heat	56.4	-9	+.5	22.5	40.3	-6.4	+	5.8	46.0	60.6	-	.5	-	-2.4	13.2	63.0	-4.7	-	-.5	14.2	-	-	-	-
I.	Electric tumbler, high heat	52.6	+2.1	-5.7	16.5	22.3	+	9	-36.7	.6	50.4	0	-	-15.5	4.1	52.6	-2.2	-	-15.1	3.7	-	-	-	-	
		Blue cotton terry						Violet acetate-viscose rayon crepe						Yellow cotton terry						Yellow cotton terry					
A.	Outside line: <sup>6</sup>	46.8	-8.5	-15.8	-	-	-	23.5	+16.9	-29.6	-	-	-	71.4	-5.4	+38.3	-	-	-	71.4	-5.4	+38.3	-	-	-
A.	Unprotected from sun	50.2	-6.5	-12.8	4.0	45.6	+6.3	-	-14.6	25.9	71.1	-	4.4	-	+31.3	6.8	-	-	-	-	-	-	-	-	-
A.	Protected from sun	49.8	-6.4	-13.2	3.5	44.7	+5.8	-	-14.8	25.0	70.7	-	4.0	-	+31.8	7.0	-	-	-	-	-	-	-	-	-
D.	Electric tumbler	52.4	-9.3	-9.1	8.9	40.4	+8.0	-	-15.1	22.0	68.3	-	3.9	-	+31.4	7.2	-	-	-	-	-	-	-	-	-
E.	Gas tumbler	58.4	-11.1	+.8	18.6	40.7	+6.5	-	-11.3	25.7	67.7	-	3.7	-	+32.1	6.7	-	-	-	-	-	-	-	-	-
H.	Gas tumbler, high heat	61.0	-10.5	+1.6	20.4	44.1	+4.6	-	-7.2	30.7	68.1	-	3.5	-	+32.5	6.1	-	-	-	-	-	-	-	-	-
I.	Electric tumbler, high heat	47.1	-6.0	-16.2	2.4	40.6	+9.4	-	-14.4	22.2	65.2	-	2.8	-	+30.4	9.2	-	-	-	-	-	-	-	-	-

<sup>1</sup> Diffuse reflectance (MgO white = 100.0)<sup>2</sup> Redness in plus direction, greenness in minus direction<sup>3</sup> yellowness in plus direction, blueness in minus direction

<sup>4</sup> See p. 7 for formula to calculate  $\Delta E$ , color change in NBS units. Change for each drying method was calculated from differences between readings at 50 dryings and the original of the swatches used in that method.

<sup>5</sup> Average length of time loads hung on outside lines was approximately 2½ hours each drying.

# EFFECT OF CERTAIN FACTORS ON PERFORMANCE OF DRYERS

In the study of dryer performance the effects of three design features were evaluated: Operating voltage, type of drum—perforated and non-perforated, and thermostat setting. Since the kind of materials making up the load to be dried, the weight of the load, and its moisture content may influence the performance of a dryer, the effect of these use factors also was studied.

## Voltage of Dryers

Two dryers alike in design, but operating with different voltages, were obtained from each of two manufacturers, in order to compare effects on fabrics dried, as well as to note the time and electrical energy required for drying. One dryer of each pair was designed for 220–240 volts and the other for 110–120; one pair D–F had nonperforated, synthetic-enameled and the other I–J had perforated, porcelain-enameled drums. The 240-

volt dryer of each pair reached higher temperatures than the 120-volt dryer; however, the differential was generally greater in the pair I–J than in the pair D–F.

Test fabrics for this phase of the study were white cotton broadcloth, denim, huck, jersey, percale sheeting, and terry toweling; dress weight and towel linen; nylon crepe and tricot; and acetate-viscose rayon crepe. Two swatches from each fabric combined with plain cotton squares to make 8 pounds dry weight were used in each dryer load. The new fabrics received the pretreatment described previously (pages 5 and 7) and swatches were randomly assigned to loads.

Before each drying, loads were washed in an automatic washer for 5 minutes in a 0.1-percent detergent solution at 140° F., and rinsed with a spray and one deep overflow rinse. The final spin was controlled to leave moisture in the load to equal  $85 \pm 2$  percent of its dry weight.

Effects were measured in terms of color, bursting strength, fluidity, and appearance. All

TABLE 10.—*Initial  $R_d^1$  and  $R_d$  change <sup>2</sup> of 11 white fabrics dried in 120- and 240-volt dryers after being washed in a detergent solution*

Drying condition	Cotton						Linen		Nylon		Acetate-viscose rayon crepe
	Broad-cloth	Denim	Huck	Jersey	Percale sheeting	Terry	Dress weight	Crash toweling	Crepe	Tricot	
Initial $R_d$											
	88.1	85.9	84.5	88.2	89.5	89.4	77.5	80.8	91.2	83.3	91.4
Change after 50 dryings											
D. 240-volt	+0.4 <sup>a</sup>	0 <sup>a</sup>	+0.4 <sup>a</sup>	-2.2 <sup>a</sup>	-2.3	-3.5 <sup>a</sup>	+4.5 <sup>a</sup>	+0.7 <sup>ab</sup>	-1.9 <sup>ab</sup>	+1.0 <sup>a</sup>	-5.2 <sup>ab</sup>
F. 120-volt	-2 <sup>a</sup>	-1 <sup>a</sup>	+.5 <sup>a</sup>	-2.5 <sup>ab</sup>	-3.0 <sup>a</sup>	-3.5 <sup>a</sup>	+4.5 <sup>a</sup>	+1.4 <sup>a</sup>	-1.6 <sup>a</sup>	+.6 <sup>a</sup>	-3.8 <sup>a</sup>
I. 240-volt, high heat	-1 <sup>a</sup>	-6 <sup>b</sup>	-5 <sup>a</sup>	-3.0	-2.8 <sup>a</sup>	-3.2 <sup>a</sup>	-1.3	-3.1	-3.7	-1.0	-5.8 <sup>b</sup>
J. 120-volt, high heat	+2 <sup>a</sup>	-6 <sup>b</sup>	0 <sup>a</sup>	-2.6 <sup>b</sup>	-3.0 <sup>a</sup>	-3.4 <sup>a</sup>	+3.4	0 <sup>b</sup>	-2.2 <sup>b</sup>	-.3	-5.1 <sup>ab</sup>
Change after 100 dryings											
D. 240-volt	-0.5 <sup>a</sup>	-0.6 <sup>c</sup>	-0.4 <sup>b</sup>	-3.6 <sup>a</sup>	-3.3 <sup>a</sup>	-5.0 <sup>a</sup>	+3.5 <sup>a</sup>	-1.0	-2.7 <sup>a</sup>	-1.8 <sup>a</sup>	-5.2 <sup>a</sup>
F. 120-volt	-9 <sup>a</sup>	-1.2 <sup>ab</sup>	-8 <sup>ab</sup>	-4.4 <sup>c</sup>	-4.1 <sup>b</sup>	-5.3 <sup>a</sup>	+3.6 <sup>a</sup>	+.3	-2.4 <sup>a</sup>	-1.6 <sup>a</sup>	-4.8 <sup>a</sup>
I. 240-volt, high heat	-6 <sup>a</sup>	-1.0 <sup>bc</sup>	-1.2 <sup>a</sup>	-3.8 <sup>ab</sup>	-3.4 <sup>a</sup>	-3.7	-3.6	-4.9	-5.2	-2.6 <sup>a</sup>	-4.9 <sup>a</sup>
J. 120-volt, high heat	-3 <sup>a</sup>	-1.5 <sup>a</sup>	-1.1 <sup>a</sup>	-4.0 <sup>bc</sup>	-4.0 <sup>b</sup>	-4.8 <sup>a</sup>	+.7	-2.8	-4.0	-1.6 <sup>a</sup>	-5.2 <sup>a</sup>

<sup>1</sup> Diffuse reflectance, measured with Hunter Color and Color-Difference Meter; MgO white=100.0.

<sup>2</sup> Reflectance change: Lighter in plus direction; darker in minus direction.

NOTE.—Data for a fabric after 50 or 100 dryings marked with the same superscript were not significantly different at the 5-percent level of probability.

measurements were made on original fabrics and after 50 and 100 dryings, except fluidity which was determined only after 100 dryings and on only 4 fabrics.

*Color.*—No definite pattern of graying or yellowing developed as a result of differences in the operating voltages (tables 10 and 11). In general, the 240-volt dryers caused more yellowing in the nylons, acetate-viscose rayon, and linen than the 120-volt. In cottons one of the 120-volt dryers frequently caused more yellowing.

*Bursting strength.*—The operating voltages had no significantly different effects on bursting strength of the fabrics (table 12).

*Chemical degradation.*—Dryer I (240-volt) caused significantly greater chemical degradation than the other three dryers (table 13). Since the other 240-volt dryer appeared in the group that were not significantly different from each other,

the damage could not be considered strictly an effect of voltage. The fact that air temperatures inside the drum and fabric temperatures in dryer I were higher than in the other three may explain the greater degradation in this dryer. Fluidity data were not in the same order of magnitude as the bursting-strength data.

*Visual judgments.*—From the 11 fabrics dried 100 times, 6 were selected for visual judging by 4 people. Judgments were made as explained on page 8, except that ranking and scoring were done at separate sessions. The scores on appearance of these 6 fabrics (table 14) agreed relatively with the Color and Color-Difference Meter measurements of reflectance and yellowing (tables 10 and 11). From all dryers, 3 cotton fabrics were scored highly satisfactory; from one 120-volt and one 240-volt dryer of like design the acetate-viscose rayon crepe and nylon tricot were

TABLE 11.—*Initial b<sup>1</sup> and b change<sup>2</sup> of 11 white fabrics dried in 120- and 240-volt dryers after being washed in a detergent solution*

Drying condition	Cotton						Linen		Nylon		Acetate-viscose rayon crepe
	Broad-cloth	Denim	Huck	Jersey	Percale sheeting	Terry	Dress weight	Crash toweling	Crepe	Tricot	
Initial b											
	+1.7	+6.6	+3.8	+2.7	+2.8	+1.9	+8.7	+7.4	+2.8	+3.6	+3.5
Change after 50 dryings											
D. 240-volt	-2.7 <sup>a</sup>	-6.2 <sup>a</sup>	-3.9 <sup>a</sup>	-2.8 <sup>a</sup>	-3.2	-5.1	-4.1 <sup>a</sup>	-4.2 <sup>a</sup>	+0.8	+1.1 <sup>a</sup>	+1.8
F. 120-volt	-2.0	-5.7 <sup>a</sup>	-3.7 <sup>a</sup>	-2.2 <sup>b</sup>	-2.8	-4.5	-4.4 <sup>a</sup>	-4.4 <sup>a</sup>	+.4	+.8	+.9 <sup>a</sup>
I. 240-volt, high heat	-2.6 <sup>a</sup>	-6.6 <sup>a</sup>	-3.1	-2.3 <sup>b</sup>	-3.5	-5.4	-.7	-1.0	+3.5	+3.5	+.8 <sup>a</sup>
J. 120-volt, high heat	-2.9	-6.6 <sup>a</sup>	-3.7 <sup>a</sup>	-2.7 <sup>a</sup>	-3.9	-6.0	-4.0 <sup>a</sup>	-3.4	+1.1	+1.2 <sup>a</sup>	+.6 <sup>a</sup>
Change after 100 dryings											
D. 240-volt	-1.8 <sup>a</sup>	-6.1	-3.6	-2.4 <sup>a</sup>	-3.3 <sup>a</sup>	-4.3	-3.6 <sup>a</sup>	-3.7 <sup>a</sup>	+6.0 <sup>b</sup>	+8.8	+12.2
F. 120-volt	-1.7 <sup>a</sup>	-5.6	-3.1 <sup>ab</sup>	-1.8 <sup>b</sup>	-2.8	-3.8	-3.7 <sup>a</sup>	-3.3 <sup>a</sup>	+4.0 <sup>a</sup>	+6.2 <sup>a</sup>	+10.2
I. 240-volt, high heat	-1.8 <sup>a</sup>	-6.8 <sup>a</sup>	-3.0 <sup>b</sup>	-1.9 <sup>b</sup>	-3.1 <sup>b</sup>	-4.8	-.6	-.7	+6.2 <sup>b</sup>	+6.5 <sup>a</sup>	+3.4 <sup>a</sup>
J. 120-volt, high heat	-2.1	-6.6 <sup>a</sup>	-3.4 <sup>a</sup>	-2.2 <sup>a</sup>	-3.2 <sup>ab</sup>	-5.5	-3.0	-2.6	+3.7 <sup>a</sup>	+4.6	+3.7 <sup>a</sup>

<sup>1</sup> Yellowness in plus direction, blueness in minus direction; measured with Hunter Color and Color-Difference Meter.

<sup>2</sup> Yellow-blue change: Toward yellow in plus direction, toward blue in minus direction.

NOTE.—Data for a fabric after 50 or 100 dryings marked with the same superscript were not significantly different at the 5-percent level of probability.

TABLE 12.—Initial and final bursting strength of 11 white fabrics dried in 120- and 240-volt dryers after being washed in a detergent solution

Drying condition	Cotton						Linen		Nylon		Acetate viscose rayon crepe
	Broad-cloth	Denim	Huck	Jersey	Percale sheeting	Terry	Dress weight	Crash toweling	Crepe	Tricot	
Initial bursting strength											
	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
	115.3	139.8	180.3	74.4	157.2	140.4	272.4	245.5	184.8	164.3	93.6
After 50 dryings											
D. 240-volt	114.0 <sup>ab</sup>	127.1 <sup>a</sup>	166.0 <sup>a</sup>	74.6 <sup>a</sup>	162.6 <sup>a</sup>	145.5 <sup>a</sup>	238.8 <sup>a</sup>	197.0 <sup>a</sup>	171.4 <sup>ab</sup>	150.7 <sup>a</sup>	69.0 <sup>a</sup>
F. 120-volt	118.2 <sup>a</sup>	126.9 <sup>a</sup>	158.6 <sup>a</sup>	73.3 <sup>a</sup>	158.0 <sup>a</sup>	150.4 <sup>a</sup>	238.9 <sup>a</sup>	197.6 <sup>a</sup>	175.2 <sup>a</sup>	153.1 <sup>a</sup>	72.1
I. 240-volt, high heat	109.9 <sup>b</sup>	136.2 <sup>a</sup>	159.5 <sup>a</sup>	76.4 <sup>a</sup>	158.6 <sup>a</sup>	150.6 <sup>a</sup>	234.6 <sup>a</sup>	215.6 <sup>a</sup>	166.2 <sup>c</sup>	150.7 <sup>a</sup>	68.1 <sup>a</sup>
J. 120-volt, high heat	117.4 <sup>a</sup>	130.3 <sup>a</sup>	155.6 <sup>a</sup>	76.2 <sup>a</sup>	163.0 <sup>a</sup>	155.0 <sup>a</sup>	242.3 <sup>a</sup>	210.5 <sup>a</sup>	168.8 <sup>bc</sup>	149.4 <sup>a</sup>	70.1 <sup>a</sup>
After 100 dryings											
D. 240-volt	95.5 <sup>a</sup>	131.9 <sup>a</sup>	156.9 <sup>a</sup>	76.5 <sup>a</sup>	147.8 <sup>a</sup>	136.4 <sup>a</sup>	206.9 <sup>a</sup>	185.2 <sup>a</sup>	167.7 <sup>a</sup>	150.8 <sup>a</sup>	64.6 <sup>a</sup>
F. 120-volt	92.9 <sup>a</sup>	124.6 <sup>a</sup>	134.8 <sup>a</sup>	69.7	136.8 <sup>b</sup>	135.8 <sup>a</sup>	207.3 <sup>a</sup>	159.5 <sup>b</sup>	166.1 <sup>a</sup>	150.1 <sup>a</sup>	64.6 <sup>a</sup>
I. 240-volt, high heat	94.6 <sup>a</sup>	126.2 <sup>a</sup>	156.9 <sup>a</sup>	74.7 <sup>a</sup>	145.0 <sup>ab</sup>	134.3 <sup>a</sup>	210.1 <sup>a</sup>	180.6 <sup>ab</sup>	156.4	147.0 <sup>a</sup>	58.4
J. 120-volt, high heat	96.6 <sup>a</sup>	128.7 <sup>a</sup>	153.1 <sup>a</sup>	77.6 <sup>a</sup>	152.7 <sup>a</sup>	132.9 <sup>a</sup>	219.2 <sup>a</sup>	179.8 <sup>ab</sup>	165.3 <sup>a</sup>	147.7 <sup>a</sup>	64.2 <sup>a</sup>

NOTE.—Data for a fabric after 50 or 100 dryings marked with the same superscript were not significantly different at the 5-percent level of probability.

considered unsatisfactory, and from the other 240-volt dryer the nylon tricot and dress linen were unsatisfactory.

*Time and energy.*—The mean time and energy consumption of the 4 dryers for 100 loads were as follows:

Dryer:	Time	Energy consumption
	Hr. Min.	Kw.-hr.
D (240-v)	1 13	4.81
F (120-v)	2 58	4.85
I (240-v)	0 58	3.68
J (120-v)	2 10	3.87

The low-voltage dryers required more than twice as much time as the higher voltage dryers of like design to dry loads of the same size and moisture content.

Each 240-volt dryer used approximately the same electrical energy per load as the corresponding 120-volt dryer; one pair of like design, however, used approximately 1 kilowatt-hour more than the other pair.

TABLE 13.—Fluidity of selected white cotton fabrics dried 100 times in 120- and 240-volt dryers after being washed in a detergent solution

Drying condition	Broad-cloth	Huck	Jersey	Percale sheeting
	<i>Rhes</i>	<i>Rhes</i>	<i>Rhes</i>	<i>Rhes</i>
D. 240-volt	7.7 <sup>a</sup>	4.8 <sup>a</sup>	5.8 <sup>b</sup>	9.4 <sup>a</sup>
F. 120-volt	6.8 <sup>b</sup>	4.4 <sup>a</sup>	5.5 <sup>ab</sup>	9.5 <sup>a</sup>
I. 240-volt, high heat	10.9	7.3	7.9	13.8
J. 120-volt, high heat	7.6 <sup>a</sup>	4.9 <sup>a</sup>	6.0 <sup>b</sup>	9.6 <sup>a</sup>
No treatment (original fabric)	6.5 <sup>b</sup>	4.4 <sup>a</sup>	4.6 <sup>a</sup>	8.6

NOTE.—Data for a fabric marked with the same superscript were not significantly different at the 5-percent level of probability.

TABLE 14.—*Judges' scores<sup>1</sup> of acceptability of appearance of 6 white fabrics dried 100 times in 120- and 240-volt dryers after being washed in a detergent solution*

Drying condition	Cotton			Linen, dress weight	Nylon, tricot	Acetate- viscose rayon crepe
	Jersey	Percale sheeting	Terry			
D. 240-volt	4.5	4.8	4.8	4.4	1.5	1.2
F. 120-volt	4.5	4.5	4.9	4.5	2.8	1.4
I. 240-volt, high heat	4.6	4.8	4.8	2.6	3.1	3.8
J. 120-volt, high heat	4.8	4.8	4.8	3.9	3.8	3.6

<sup>1</sup> Scale for scoring: 1. Very poor (not acceptable). 2. Poor (barely acceptable). 3. Fair (could be considerably improved). 4. Good (acceptable, but would like to improve it). 5. Very good (would not attempt to improve it). Data are averages of the scores of 4 judges.

### Type of Drum

Data obtained on electric dryers D and G (medium setting) in the study of the effect of drying method on selected white fabrics were used to compare the performance of perforated- and nonperforated-drum dryers (tables 2, 3, 4, 5, 6). Melting temperatures of the temperature-indicating crayon marks included in the loads showed these dryers to be comparable in operating temperature (table 15).

**Color.**—The nonperforated-drum dryer caused greater loss of reflectance than the perforated in all but 2 (nylon crepe and acetate-viscose rayon crepe) of the 14 fabrics in 50 dryings and in all but 1 (nylon crepe) in 100 dryings.

With 50 dryings the nonperforated drum caused significantly more yellowing than the perforated drum in half the fabrics, but with 100 dryings there were significant differences in only 2 fabrics. In one of them the nonperforated and in the other the perforated drum caused more yellowing. These differences were too small to be of practical significance.

**Chemical degradation.**—Drying in the two types of drums resulted in fluidity values that were not significantly different in half the fabrics; in the other half the perforated drum caused more chemical degradation, although the differences were numerically small.

**Bursting strength.**—The two types of drums were not significantly different in their effect on bursting strength of any of the fabrics dried 50 times; after 100 dryings differences were significant for only one fabric, nylon tricot.

**Dimensional change.**—The effects of the two types of drums on dimensions in the warpwise

direction were much alike for all fabrics at both intervals.

TABLE 15.—*Maximum temperatures<sup>1</sup> at three locations in automatic dryers studied*

Dryer	Location		
	Ex- haust <sup>2</sup>	Inside drum <sup>3</sup>	Strips on load <sup>4</sup>
D. Electric, 240-volt	° F.	° F.	° F.
E. Gas	172	198	150
F. Electric, 120-volt	169	232	150
G. Electric:			( <sup>5</sup> )
High heat	124	136	
Medium heat	131	186	175
Low heat	120	147	150
H. Gas:			
High heat	101	120	125
Medium heat	111	147	175
Low heat	114	171	200
I. Electric, 240-volt, high heat	131	159	175
J. Electric, 120-volt, high heat	95	139	150

<sup>1</sup> Each figure is the average of at least two replications.\*

<sup>2</sup> Thermocouple junction in lint trap.

<sup>3</sup> Thermocouple junction inside drum, 3 inches from door.

<sup>4</sup> Temperature-indicating crayon marks on fabric strips attached to pieces of load. Crayons included for 25° intervals from 150° to 275° F. More crayons melted at temperature given than at higher temperatures included. Interpret as approximate rather than absolute.

<sup>5</sup> None of the 150° F. marks melted; no lower temperature crayons were on hand.

<sup>6</sup> Highest temperature-indicating crayon mark included in load.

## Thermostat Setting

To compare the effects of high, medium, and low thermostat settings, objective measurement data on dryers G and H in the work on effects of drying methods on selected white fabrics were used (tables 2, 3, 4, 5, 6). Temperatures at the three settings at the different locations of measurement are given in table 15. A variation of fabric temperature of about 25 degrees occurred between high and medium and between medium and low thermostat settings in both dryers.

*Color.*—Comparison of data for the three thermostat settings indicated that there was little difference in their effect on the reflectance of fabrics dried 50 and 100 times in either the gas or electric dryers.

After 50 dryings on high, medium, and low settings in gas and electric dryers, the yellowing effect was significantly different for very few fabrics. Where significant differences occurred, the high setting generally had the greatest effect. Effects of medium and low settings were rarely significantly different.

After 100 dryings of the 14 fabrics in the gas dryer, high setting resulted in a yellowing effect which was not significantly different from that caused by medium and/or low settings in 11 fabrics. In the other 3 fabrics the significant difference was too small to be of practical importance. In the electric dryer no significant difference in yellowing occurred in 9 of the fabrics dried on high, medium, and low settings, nor was there a consistent order of magnitude of yellowing in the other 5 fabrics.

*Chemical degradation.*—After 100 dryings in the electric and gas dryers differences in the effects of high, medium, and low heats on the fluidity of the 14 fabrics were small, even though they proved to be statistically significant in some cases (table 4). Only the 2 nylon fabrics in the gas dryer showed consistent and substantial enough damage between effects of thermostat settings to be considered a definite trend of increasing damage as the settings were changed from low to high.

*Bursting strength.*—After 50 dryings there was no significant difference between the effects of high, medium, and low heats on bursting strength of 12 fabrics in the gas dryer and 11 in the electric. High heat in the gas dryer weakened nylon tricot more than medium and low heats; medium and high caused more loss of strength in nylon crepe

than low. In the electric dryer medium and low heats were not significantly different in this effect on nylon crepe but were more damaging than high.

With 100 dryings at each of the three temperature settings, the bursting strengths of 10 fabrics in the gas dryer and 11 in the electric were not affected in a significantly different manner. In the other fabrics in which there were differences, the effects of the three temperatures were not in a consistent pattern of magnitude.

*Dimensional change.*—The effects of the three temperatures on the warpwise dimensions of fabrics varied slightly from each other.

## Composition and Weight of Load

Many instruction books for the operation of clothes dryers recommend the separation of light and heavy fabrics before they are dried in order to have articles together which require about the same drying time.

The performance of clothes dryers with mixed fabric loads and with single fabric loads was investigated to determine the effect on drying time and the electrical energy required. Six dryers were used.

Mixed fabric loads of 3 pounds of dry sheets and 3 pounds of dry terry towels were soaked in an automatic washer. Water was extracted until the moisture content was  $85 \pm 2$  percent of the dry weight of the load. The loads were dried as they came from the washer.

For single-fabric 6-pound loads (dry weight), two wet mixed loads were separated into a terry towel load and a sheet load.

*Drying time and energy consumption.*—The two 6-pound mixed-fabric loads required an average of 82 minutes total drying time compared with 65 minutes for the same quantity in two separate single-fabric loads (table 16). The average drying time was approximately 3 minutes less for one 6-pound mixed load than for two 3-pound single-fabric loads.

The two 6-pound mixed loads required approximately 0.5 kilowatt-hour more electrical energy for drying than did the two 6-pound single-fabric loads. A 6-pound mixed load required 0.17 kilowatt-hour less for drying than the two 3-pound single-fabric loads.

In table 16 are shown specific times and electrical energy required, with quantity of moisture removed from the loads in different dryers. The

3 pounds of terry towels retained approximately twice as much moisture as the same weight of sheets, although they were spun together. Hence, both the 3- and 6-pound loads of terry towels required approximately twice as much time to dry as did the 3- and 6-pound loads of sheets.

TABLE 16.—*Amount of moisture removed in drying and time and energy required for drying mixed and separate loads of sheets and terry towels<sup>1</sup>*

Load	Dry weight	Moisture removed	Electrical energy	Time
	<i>Pounds</i>	<i>Grams</i>	<i>Kilowatt-hours</i>	<i>Minutes</i>
Mixed-----	6	2,310	2.75	41
Terry-----	6	2,962	3.35	44
Sheets-----	6	1,405	1.68	21
Terry-----	3	1,483	1.95	31
Sheets-----	3	757	.97	13

<sup>1</sup> Data are means from 6 dryers.

### Moisture Content of Load

In order to note the effect of different moisture contents of a load of household laundry on the time and heat energy required for drying, 8-pound loads of sheets and terry towels were wet to range from 50 to 140 percent of their dry weight, in increments of 15 percent. The time for drying increased, on the average, 5 minutes for each 15-percent increment. The energy for drying each 15-percent moisture increment averaged approximately 0.4 kilowatt-hour of electricity or 1.7 cubic feet of gas.

## OPERATING CHARACTERISTICS OF DRYERS

Throughout the course of the study, data were obtained on operating characteristics of the dryers under conditions of use. They included the air temperatures provided, temperatures reached by the fabrics, heat energy used in relation to amount of moisture removed from loads, and time required for drying.

*Temperatures.*—The maximum exhaust temperature in all dryers was lower than the maximum recorded inside the drum near the door (table 15). Maximum temperatures of fabrics as indicated by temperature-indicating crayon marks on the strips in the load were greater in some dryers and less in others than the temperature of the air near the

door. High and low thermostat settings in the electric dryer were 11° F. apart at the exhaust, 51° inside the drum, and 50° as indicated by the crayon marks. In the gas dryer the range in the exhaust was 10°, inside the drum 32°, and with the indicating crayon marks, 50°.

Further research is needed on methods of measurement to yield accurate determinations of temperatures reached by the fabrics and within the dryers combined with the duration of those temperatures.

*Drying time.*—Comparison of the data for time requirements for drying approximately equal loads at different thermostat settings shows that both of the dryers studied required less time on the high than on the medium setting (table 17).

TABLE 17.—*Summary of energy and time requirements for drying 8-pound loads of white fabrics by different methods*

Drying condition	Energy		Time for drying <sup>1</sup>
	Total	B. t. u. per 1,000 grams of moisture removed	
A. Outside line, unprotected from sun.			Hours 3.8
B. Inside rack-----			5.7
C. Electric cabinet-----	5.9 kw.-hr-----	6,189	4.8
D. Electric tumbler, 240-volt.	4.8 kw.-hr-----	5,010	1.2
E. Gas tumbler-----	16.8 cu. ft-----	5,348	1.3
F. Electric tumbler, 120-volt.	4.8 cu. ft-----	5,103	3.0
G. Electric tumbler:			
High heat-----	4.5 kw.-hr-----	4,684	1.0
Medium heat-----	4.4 kw.-hr-----	4,635	1.1
Low heat-----	4.5 kw.-hr-----	4,660	1.2
H. Gas tumbler:			
High heat-----	12.9 cu. ft-----	4,341	1.0
Medium heat-----	12.3 cu. ft-----	4,203	1.1
Low heat-----	11.9 cu. ft-----	4,070	1.6
I. Electric tumbler, 240-volt: High heat.	3.7 kw.-hr-----	3,901	1.0
J. Electric tumbler, 120-volt: High heat.	3.9 kw.-hr-----	4,103	2.2

<sup>1</sup> Figures given are means. For A the range was from 1.8 to 7.2 hours; for B, from 3.7 to 7.6 hours; for C, from 4.5 to 5.0 hours. For tumbler dryers, the range was within a few minutes of the mean.

For one dryer, time was considerably greater on the low than on the medium setting; for the other, operation on either setting made little difference in drying time.

As has been stated previously (page 24), the dryers operated on 120 volts required more than twice as much time to dry a load as their duplicates operated on 240 volts.

*Energy requirements.*—Operating data are reported in table 17. With the two dryers operated on high, medium, and low thermostat settings, the setting made little difference in the efficiency of operation, expressed in British thermal units of heat required per 1,000 grams of moisture removed. Data for the 120- and 240-volt dryers in each of the two pairs studied showed little difference in efficiency due to voltage. One pair of dryers (I-J) had greater efficiency than the other pair (D-F), which indicated that in this instance the design of dryers had more effect on efficiency than the voltage.

## TIME USED BY OPERATOR

Since the operator's time is a factor to be considered in an evaluation of drying methods, records were made of the time required for placing wet loads on lines or racks and in tumbler dryers and for removing the loads when dried. The times noted did not include time for folding.

The tumbler dryer, in comparison with the inside rack and cabinet dryer, saved 10.5 minutes of the operator's time in placing and removing a load; in comparison with the outside line, it saved 12.6 minutes. No time was recorded for

covering distances between washer and line or dryer; this, of course, would vary for different homes. Neither was any account made of expenditure of physical energy in moving the clothes to the place of drying.

Cleaning lint traps in dryers required a little more than half a minute; where emptying water and removing lint were both involved, the time was increased approximately 3 times.

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